Speed Control of DC Motor using MOSFET based Chopper

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Bachelor of Technology in Electrical Engineering

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CERTIFICATE

This is to certify that the progress report of the thesis entitled, "**CONTROL OF DC MOTOR USING CHOPPER"** submitted by **Shri Marripudi Laxmi Deepak & Shri Anshuman Mishra** in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Electrical Engineering at the **National Institute of Technology Rourkela, India**, is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

Prof. K.B.MOHANTY

Date: **Department of Electrical Engineering**

Place: **National Institute of Technology, Rourkela**

ACKNOWLEDGEMENT

We would like to express our deep gratitude to our project guide **Prof. K. B. Mohanty** who was the source of motivation throughout the making of this project. We express our gratitude to **Prof. A.K.Panda**, Professor and Head of the Department, Electrical Engineering for his invaluable support and encouraging attitude. At last but not the least we would like to thank all the members of NIT Rourkela who in direct and indirect ways helped us complete this project.

CONTENTS:

LIST OF FIGURES:

ABSTRACT

DC motors form the backbone of many industries and as such their speed control becomes of immense importance. It has been found that many of these applications perform with a greater efficiency when the motors are fed from a source of variable dc power. In this report we analyze the separately excited dc motor using, MATLAB (Simulink), for speeds above and below the rated speed using a chopper circuit. The chopper circuit receives a signal from the firing circuit and then gives a signal to the armature voltage controller of the separately excited dc motor and the speed is accordingly increased or decreased. In this system we use two different control loops, in for speed and another for current. Here we use a proportional integral type control as in this the delay gets removed and the control provided is very fast. The dc motor is modelled and the control loops are laid out and then onwards we design the drive system. There after the simulations of the system have been carried out and analyzed under varying circumstances of speed and load torque.

Chapter-1: Introduction

Industries are the backbone of the modern era and so it is of utmost importance that they always run with the highest possible efficiency. And for this reason many industrial applications require dc voltage sources, some by force and some by choice. However many of them perform better when they are fed from a variable dc source as compared to fixed voltage sources. These include battery operated vehicles, subway cars, battery charging etc. The conversion of fixed dc voltage to variable dc can be obtained by using semiconductor devices. Earlier this used to be achieved by AC link chopper but were costly, bulky and less efficient. This is the place where the dc chopper comes into play. Being a single stage conversion device the dc chopper has altogether heralded a new era in rapid transit systems. As most of the traction systems in India still operate via dc motors this project aims to simulate and analyze a model of dc chopper using power MOSFET and study the speed control characteristics and the advantages and limitations of using a power MOSFET.

There are basically two kinds of techniques available for speed control of separately excited dc motor

- Variable armature control for below rated speed.
- Variable field flux control for above rated speed operations.

The different methods that can be and have been used in speed control of dc motors are:

- Earlier armature voltage using rheostat was used to be varied.
- Conventional kind of PID controllers can also be used.

- Nowadays neural network controllers are also used.
- Constant power motor field weakening controller.
- Single phase uniform PWM ac-dc buck-boost converter having just one switching device is utilized in armature voltage control.
- Using NARMA-L2 (Non-linear Auto-regressive Moving Average) controller for the constant torque region.

Chapter 2- CHOPPER

2.1 DC CHOPPERS

A chopper is a particular kind of static device which is adept in converting fixed dc voltage to variable dc voltage. Earlier ac link choppers were used for converting fixed dc to variable dc but those were bulky and inefficient as they involved multi step conversion. But with the introduction of dc choppers things have changed. These are single step static devices and hence are more efficient and less bulky and are available in a lower price tag.

With the intervention of choppers the efficiency of dc machine systems have increased to a great extent and as such the dc choppers have become a key component of the modern dc applications and as a whole of the entire industry employing dc power. Nowadays choppers have become an essential component of rapid transit systems. They have also found extensive applications in mine haulers, forklift trucks and marine hoists. They are also used in hybrid electric vehicles as they provide the regenerative braking facility.

A power semiconductor device is used as a switch in the overall chopper circuitry. This device can be a MOSFET, a GTO or an IGBT. These power electronic devices have a voltage drop of around 0.5-2.5 volts which has been neglected as such in the analysis carried out in this project report.

2.2 PRINCIPLE OF CHOPPER OPERATION

Chopper is basically a very high speed on/off switching device. Its basic job is to connect and disconnect the load from source at a great speed. In this way the constant dc voltage is chopped and we obtain a variable dc voltage. There are basically two time periods in chopper operation, one is the "on" time denoted as T_{ON} and other is the "off" time denoted as T_{OFF}. During T_{ON} we get the constant source voltage V_S across the load and during T_{OFF} we get zero voltage across the load. The chopper plays the role of providing this pattern of providing alternate zero and V_S. In this way we obtain a chopped dc voltage in the load terminals.

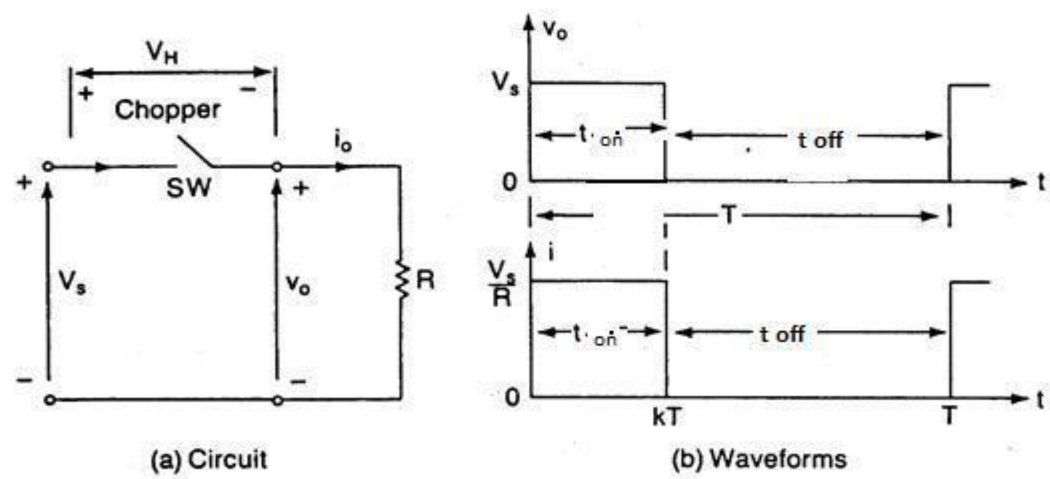

FIGURE 1 (A) BASIC CHOPPER CIRCUIT (B) VOTAGE WAVEFORMS

V_O = Average output voltage of the circuit

V_S = Source voltage of the circuit

$V_O = T_{ON} / (T_{ON} + T_{OFF}) \times T_{ON}$ (2.1)

$T_{ON} / (T_{ON} + T_{OFF})$ = Duty cycle denoted by α.

Thus we see that we can control the average output voltage by varying the duty cycle.

2.3 CONTROL STRATEGIES

We observed that the average output voltage can be controlled by varying the duty cycle of the chopper circuit. So the task in front of ourselves is basically to vary the duty cycle so as to get the required voltage output. Two modes exist which can help us in varying the duty cycle of the system in order to get the required output voltage. The two control strategies existent are:

- Time ratio control (TRC)
- Current limit control (CLC)

2.3.1 Time ratio control- in this method we vary the time ratio. This can done in two ways:

- Constant frequency system
- Variable frequency system

Constant frequency system- in this method we vary the on time of the system but as a whole the chopping frequency or we can say the time period is kept constant. Basically in this method we are varying the width of the pulse and as such this method is also known as PULSE WIDTH MODULATION.

Variable frequency system- In this method we are varying the chopping frequency, that is, we are varying the time period of the system but in doing so we are keeping either the T_{ON} or T_{OFF} constant.

2.3.2 Current limit control- in this method of control the turn on and off times of the chopper circuit is determined by the former value of load current. The previous maxima and minima of the load current act as set values and decide the on and off time of the chopper circuit. When the current in through the load crosses the maxima the device is switched off and when it falls below the minima the device is switched on. However this method is very tedious and complicated as it involves the feedback loops and hence the triggering circuit for this mode of operation becomes very complex and as such PWM method is generally the preferred mode of operation.

2.4 MOSFET

MOSFET is nowadays the most preferred switching device used in the chopper circuits. MOSFET is a voltage controlled device and has zero storage time. MOSFET is highly suitable for high frequency switching and as such is widely used because of absence of minority carrier storage time.

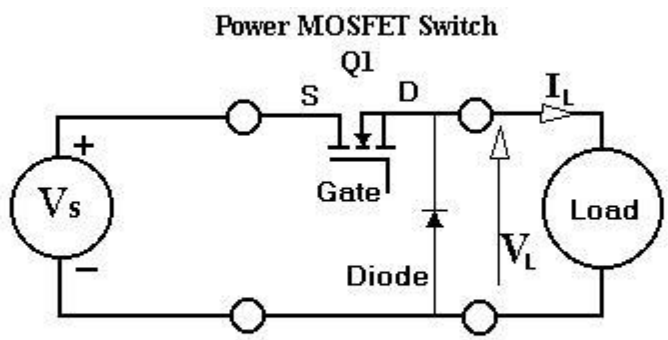

FIGURE 2 BASIC CHOPPER CIRCUIT

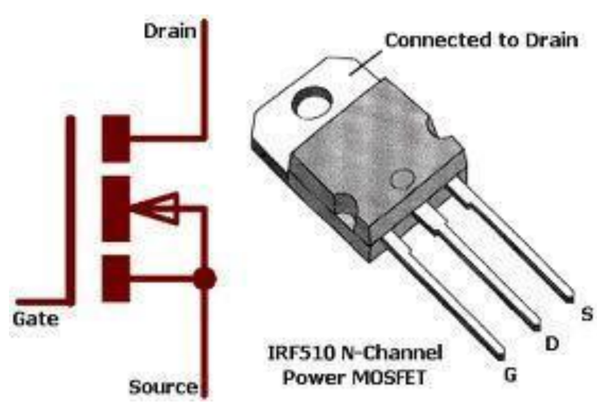

FIGURE 3(A) CIRCUIT DIAGRAM OF MOSFET (B) POWER MOSFET

CHAPTER 3 SEPARATELY EXCITED DC MOTOR

3.1 INTRODUCTION

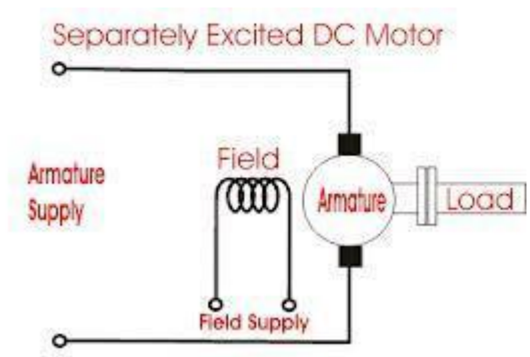

FIGURE 4 SEPARATELY EXCITED DC MOTOR

In a separately excited dc motor the armature winding and the field winding is supplied from two different sources. The current flows in the field winding and produces the flux which in turn interacts with the armature current and results in the formation of the torque.

3.2 EQUATIONS INVOLVED

Field current:

$$V_F = R_F I_F + L_F\_\_\_ \qquad (3.1)$$

Where R_F and L_F are the field resistance and inductance respectively.
Armature current: $= \ + \qquad \_\_\_$

(3.2)

Where R_A and L_A are armature resistance and inductance respectively.

Back EMF:

$$E_G = K_V W I_F$$

(3.3)

Where K_V is the armature voltage constant and W is the speed of rotation.

Torque developed in the machine is expressed as:

$$T_D = K_T I_F I_A$$

(3.4)

Where K_T is the torque constant which is assumed to be equal to be K_V

Sometimes we also express the torque developed as

$$T_D = K_T I_A Ø \tag{3.5}$$

Where Ø is the flux produced.

The developed torque is also expressed as the sum of load torque, inertia and component of friction.

$$T_D = T_L + J\frac{}{} + BW \tag{3.6}$$

Where J= inertia of motor

B= Vicious friction constant

T_L= Load torque

The motor speed is expressed as:

$$W = (V_A - I_A R_A)/I_F R_F \tag{3.7}$$

The required power P_D:

$$P_D = T_D W \tag{3.8}$$

3.3 SPEED CONTROL:

We can control the motor speed by using the following two methods:

- Armature voltage control
- Field flux control

When the first method is used the field is kept constant and when the second method is used the voltage is kept constant. First method is used for values below rated speed and the second is used for values above rated speed.

3.4 RATED SPEED AND FIELD WEAKENING:

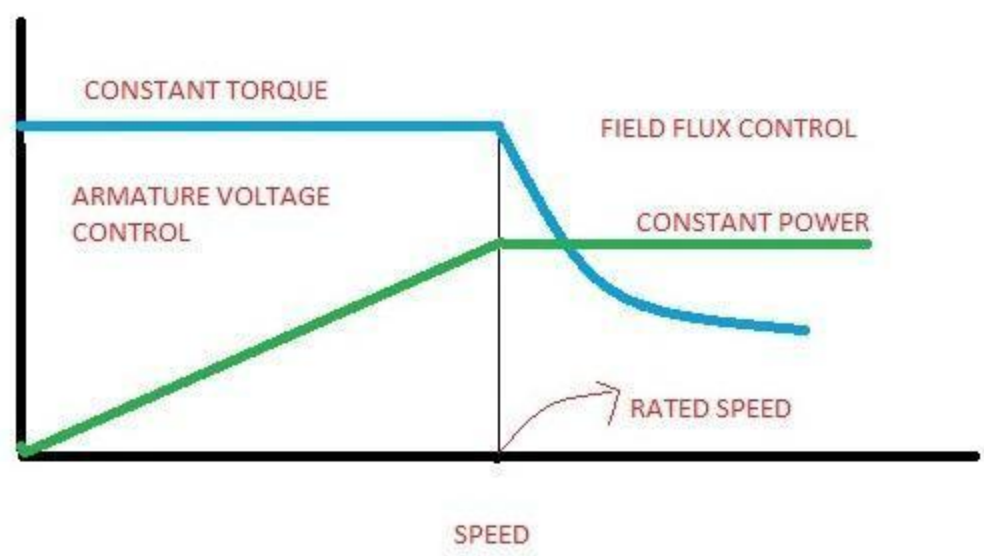

FIGURE 5 REGION OFCONSTANT TORQUE AND POWER

RATED SPEED- The speed which corresponds to the rated values of armature voltage, armature current and field current.

CONSTANT TORQUE REGION- the region below rated speed is the constant torque region and in this region we achieve speed control by varying the armature voltage. In this region the torque is constant while the power rises linearly with speed.

CONSTANT POWER REGION- the region above the rated speed is the constant power region. In this region the speed is varied by varying the field flux. Here the torque gradually decreases but the power remains constant. By decreasing the field flux we are gradually increasing the speed hence this is known as Field Weakening.

Chapter 4 MODELLING OF THE MOTOR

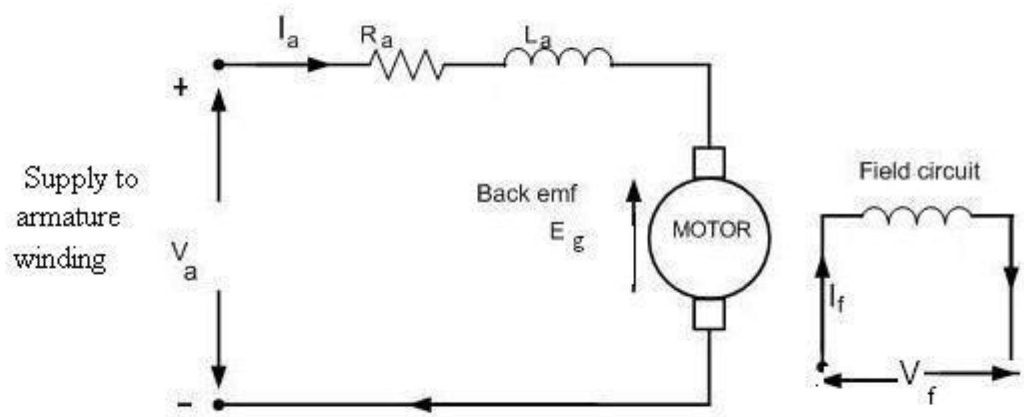

FIGURE 6 MODELLING OF MOTOR

Armature voltage equation = + —— (4.1)

Torque equation:

$$T_D = T_L + J\frac{}{} + BW \quad (4.2)$$

Here we assume that there is negligible friction present in the rotor of the motor and so we assume B = 0. Therefore:

$$T_D = T_L + J\frac{}{} \quad (4.3)$$

Back EMF of the motor is given by:

$$E_G = K_V W I_F \quad (4.4)$$

Taking Laplace transform of the armature current equations we get:

$$I_A(S) = (V_A - E_G) / (R_A + L_A(S)) \quad (4.5)$$

Now by replacing E_G we get:

$$I_A(S) = (V_A - K_V W I_F) / (R_A + L_A (S)) \quad (4.6)$$

But $E_G = K_V Ø W$ also, so:

$$I_A(S) = (V_A - K_V Ø W) / (R_A + L_A (S)) \quad (4.7)$$

$$I_A(S) = (V_A - K_V Ø W) / R_A (1 + L_A (S)/ R_A) \quad (4.8)$$

And $$W(S) = (T_D - T_L)/JS = (K_T I_A Ø - T_L)/JS \quad (4.9)$$

Here we get the armature time constant as $T_A = L_A/R_A$

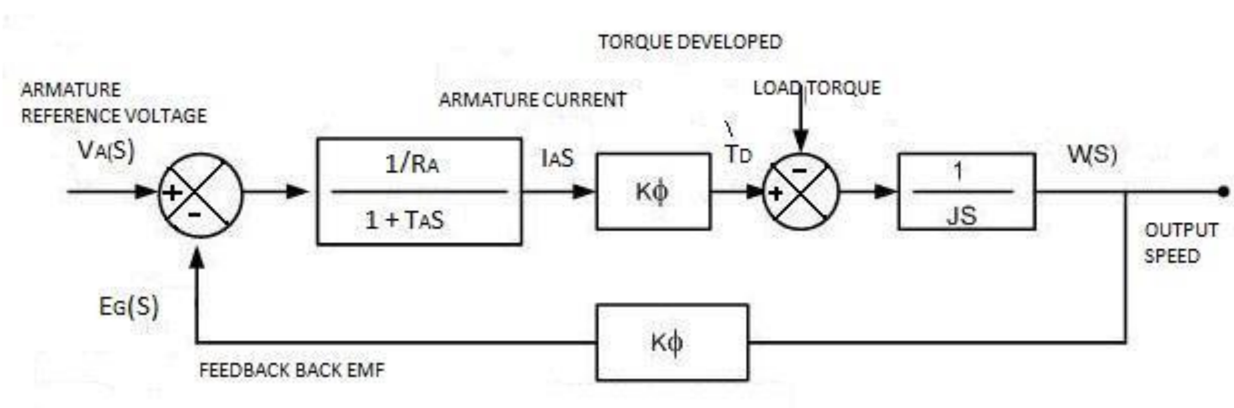

FIGURE 7 BLOCK DIAGRAM OF SEPARATELY EXCITED DC MOTOR

Upon simplification we get the overall transfer function of the above system as:

$$W(S)/V_A(S) = [KØ/R_A]/JS (1+ T_A S)/ [1+ K^2Ø^2/R_A)/JS (1+T_A S)] \quad (4.10)$$

Further simplification yields:

$$W(S) /V_A(S) = (1 /KØ) / \{1 + (K^2Ø^2 /R_A) /JS (1+T_A S)\} \quad (4.11)$$

Introducing electromechanical time constant T_M as $JR_A / (KØ)^2$

We get

$$W(S)/V_A(S) = (1/KØ) / [ST_M (1+ST_A) + 1] \quad (4.12)$$

Assuming that at the point of starting the load torque is zero and armature inductance is negligible

$$V_A = K \times Ø \times W (T) + I_A R_A \quad (4.13)$$

Now the torque equation becomes:

$$T_D = J\overline{\quad} = K\text{Ø}I_A \tag{4.14}$$

Replacing the value of I_A in the above equation:

$$V_A = K \times \text{Ø} \times W\,(T) + (J\overline{\quad})\,R_A/K\text{Ø} \tag{4.15}$$

Dividing both sides of the above equation with KØ, we get:

$$V_A/K\text{Ø} = W\,(T) + R_A\,J\overline{\quad}/\,(K\text{Ø})^2 \tag{4.16}$$

$V_A/K\text{Ø}$ equals the motor speed at no load.

$$\text{Therefore, } W\,(\text{no load}) = W\,(T) + R_A\,J\overline{\quad}/\,(K\text{Ø})^2 = W\,(T) + T_M\overline{\quad} \tag{4.17}$$

Where, $K\text{Ø} = K_M$ (Assume)

And $T_M = JR_A\,/\,(K\text{Ø})^2 = JR_A/\,(K_M)^2$

$$\text{Therefore, } J = T_M\,(K_M)^2/\,R_A \tag{4.18}$$

From above and motor torque equation we get:

$$W(S) = [(R_A\,/\,K_M)\,I_A(S) - T_L\,R_A\,/\,(K_M)^2]\,(1/T_M(S)) \tag{4.19}$$

The largest time constant plays the most crucial part in delaying of the system when the transfer function is in time constant form. To recompense for the delay caused in the system we employ PI controller as speed controller. This is because the zero of the PI controller is chosen in such a manner that this huge delay gets cancelled [1].

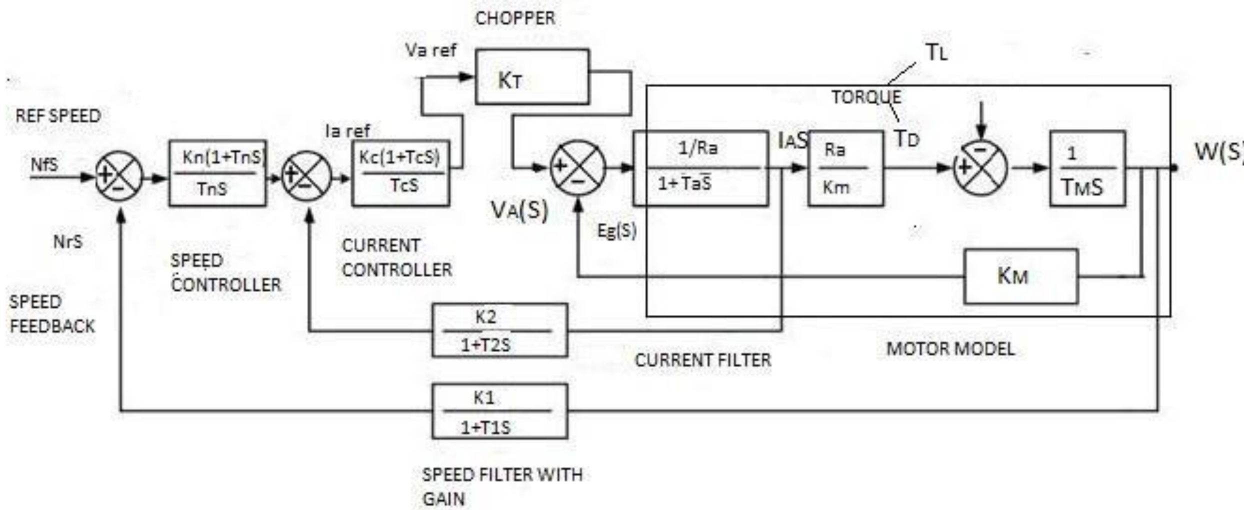

FIGURE 8 SPEED CONTROL LAYOUT

CHAPTER 5 PROBLEM STATEMENT[5]

Nameplate ratings of the dc motor used in the simulations are 320 kW, 440 v (dc) and 55 rad/sec.

Values of the parameters associated with the machine are:

- Moment of Inertia, J = 85 $Kg\text{-}m^2$.
- Back EMF Constant = 9 Volt-sec/rad.
- Rated Current = 715 A.
- Maximum Current Limit = 1000 A.
- Resistance of Armature, R_A = 0.025 ohm.
- Armature Inductance, L_A = 0.72 mH.
- Speed Feedback Filter Time Constant, T_1 = 25 ms.
- Current Filter Time Constant, T_2 = 3.5 ms.

5.1 PARAMETERS FOR CURRENT CONTROL:

Current PI type controller is given by:

$K_C (1 + T_C S)/T_C S$ here, $T_C = T_A$ and $K_C = R_A T_A / (2K_2 K_T T_2)$

$T_A = L_A/R_A = 0.72*10^{-3}/0.025 = 29.9$ ms.

For the analog circuit maximum value of controller output is ± 10 Volts.

Therefore, $K_T = 440/10 = 44$. Also, $K_2 = 10/1000 = 1/100$.

Now, putting value of R_A, T_A, K_2, K_T and T_2 we get: $K_C = 0.24$.

5.2 Parameters for speed control:

Speed PI type controller is expressed as: $K_N\{(1+T_NS)/T_NS\}$

Here, $T_N = 4\lambda = 4(T_1+2T_2) = 4(25 + 7) = 128$ ms.

And, $K = T_M K_M K_2/(2K_1 R_A \lambda)$.

$K_1 = 10/55 = 0.18$.

$T_m = JR_A/K_m = 85*0.025/9 = 22.9$ ms.

Now, $K_N = (22.9*9*1)/(2*0.18*0.025*32*100) = 6.20$

CHAPTER 6 -Results and Discussions

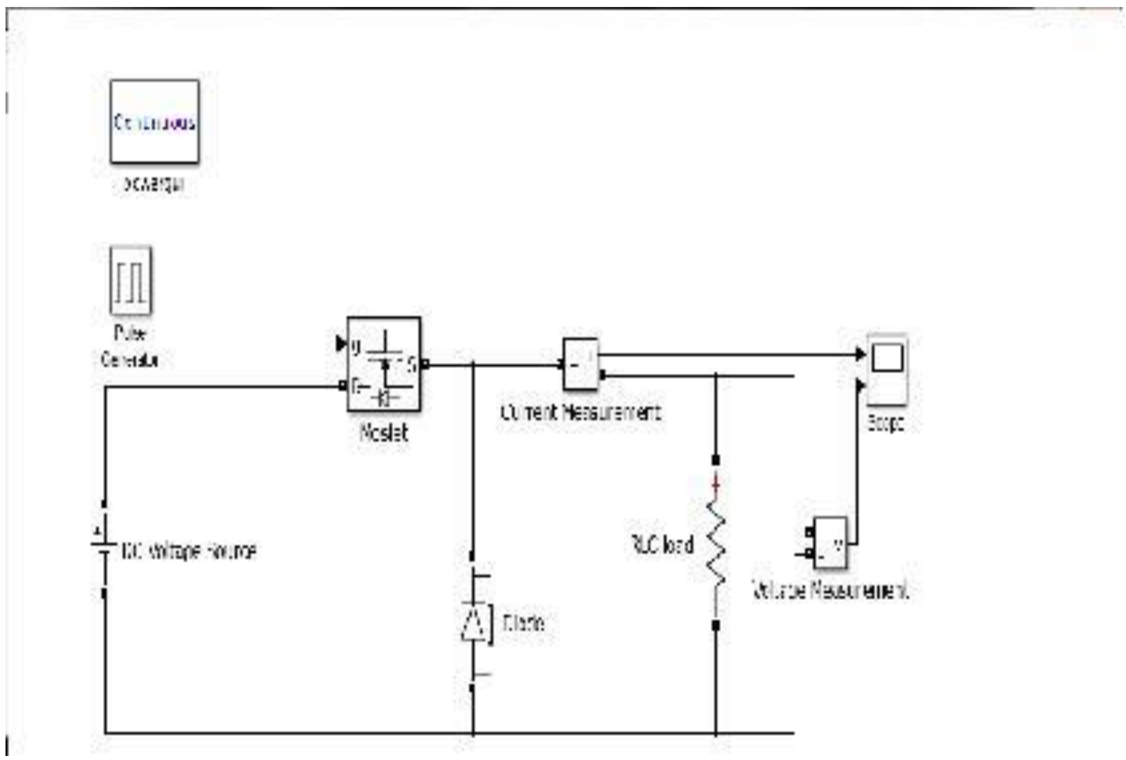

FIGURE 9 SIMULATION DIAGRAM OF DC CHOPPER

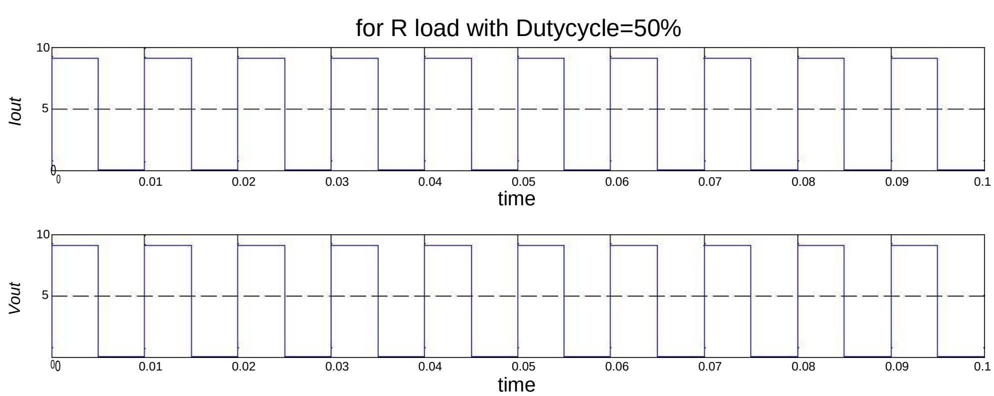

Figure 10 CURRENT AND VOLTAGE WAVEFORM AT 50% DUTY CYCLE WITH R LOAD

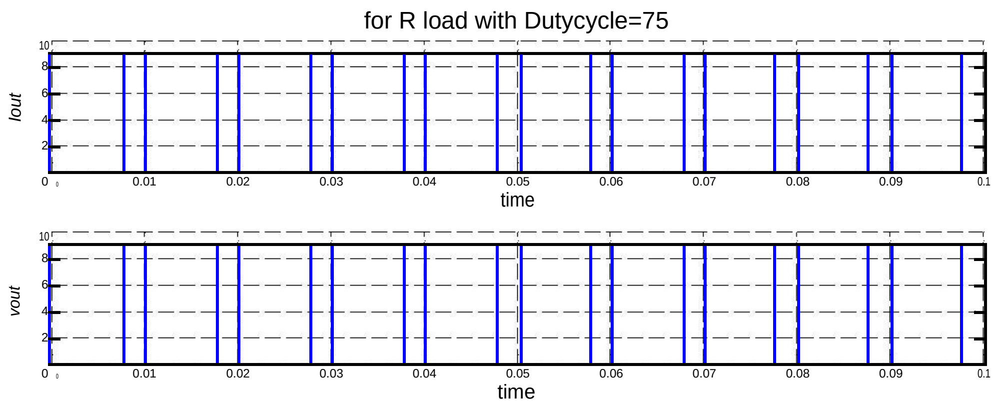

FIGURE 11 CURRENT AND VOLTAGE WAVEFORM AT 75% DUTY CYCLE WITH R LOAD

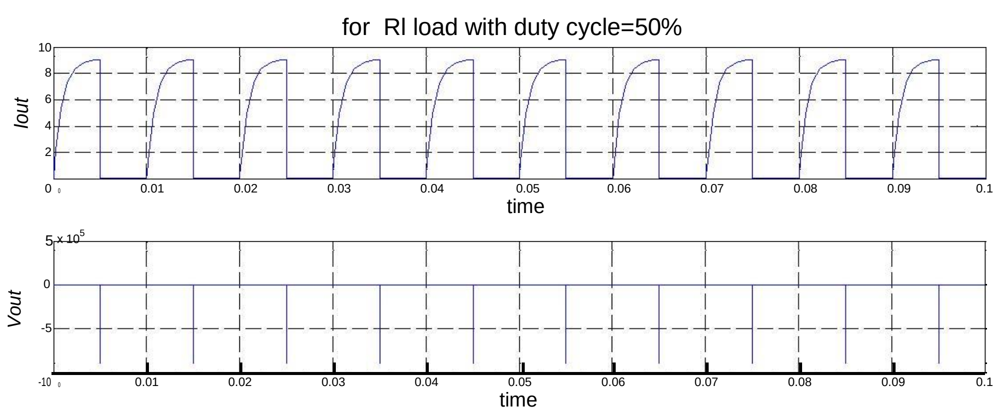

FIGURE 12 CURRENT AND VOLTAGE WAVEFORM AT 50% DUTY CYCLE WITH RL LOAD

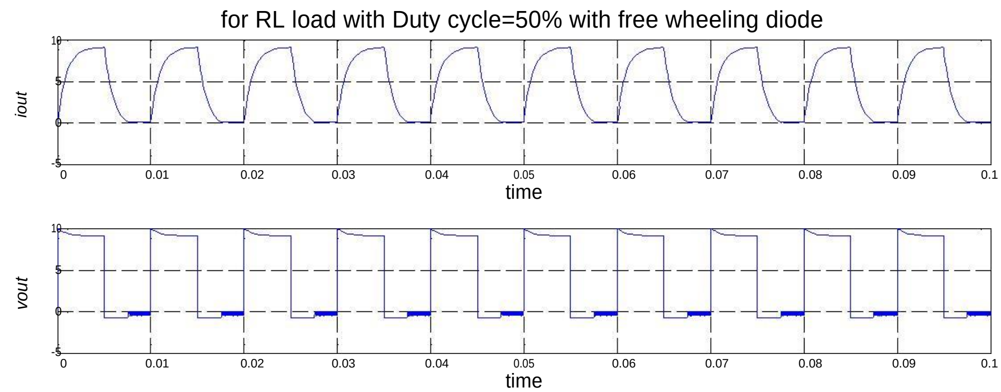

FIGURE 13 CURRENT AND VOLTAGE WAVEFORM AT 50% DUTY CYCLE WITH RL LOAD AND FREEWHEELING DIODE

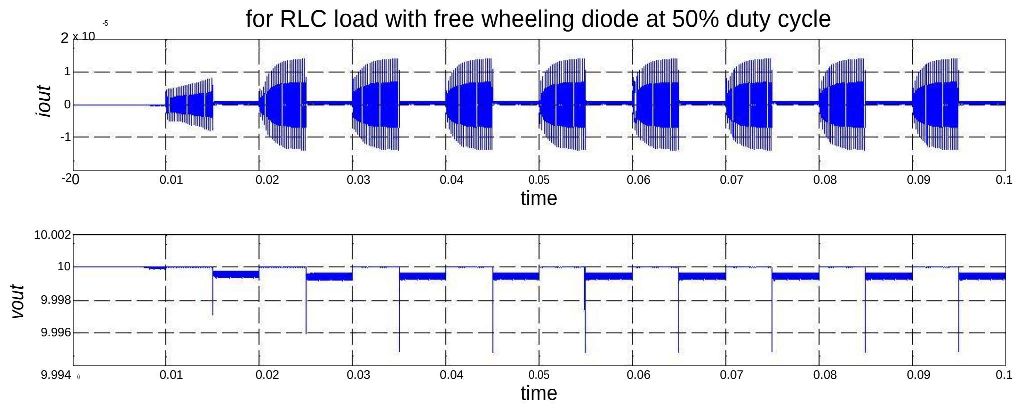

FIGURE 14 CURRENT AND VOLTAGE WAVEFORM AT 50% DUTY CYCLE WITH RLC LOAD AND FREEWHEELING DIODE

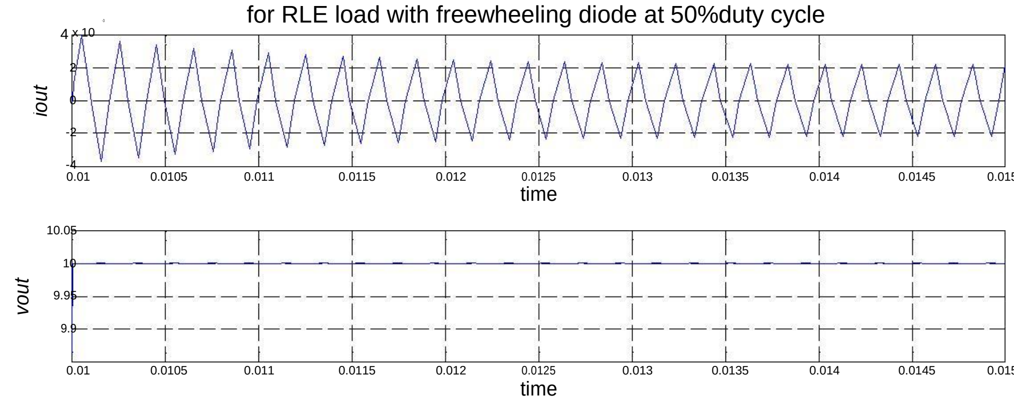

FIGURE 15 CURRENT AND VOLTAGE WAVEFORM AT 50% DUTY CYCLE WITH RLE LOAD AND FREEWHEELING DIODE

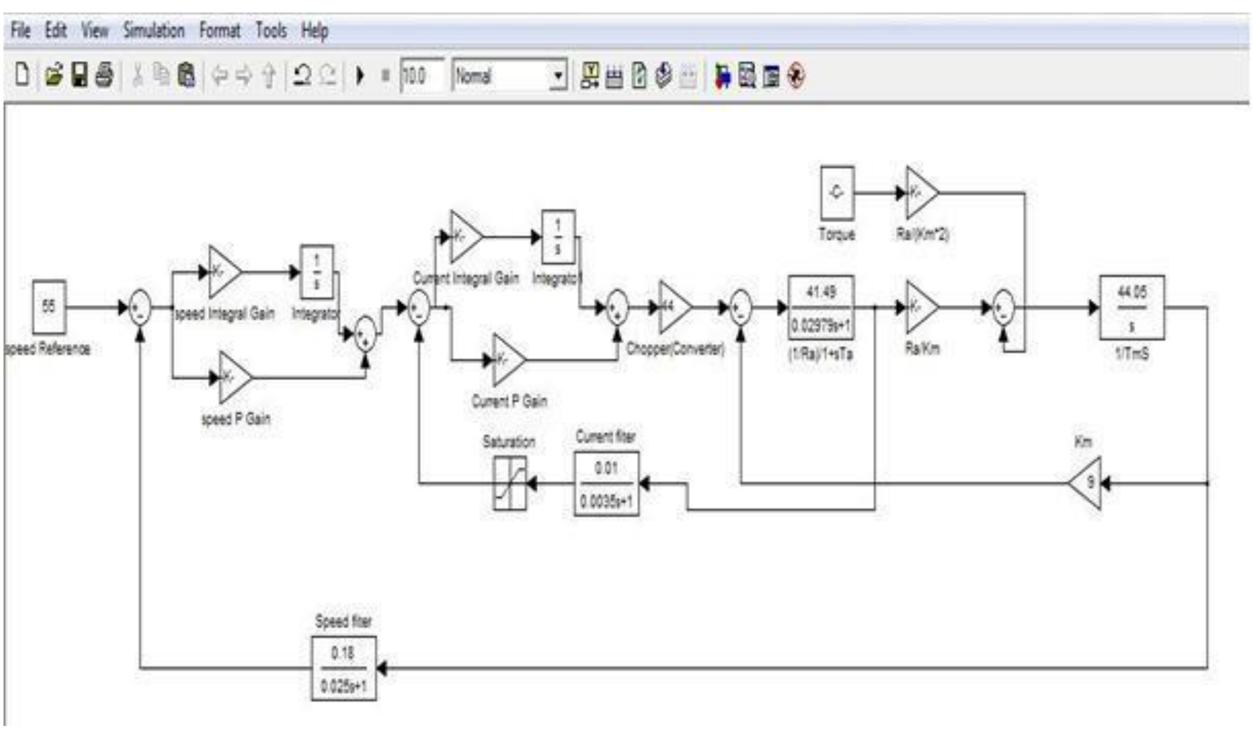

FIGURE 16 SIMULINK MODEL FOR SPEED CONTROL WITHOUT FILTER

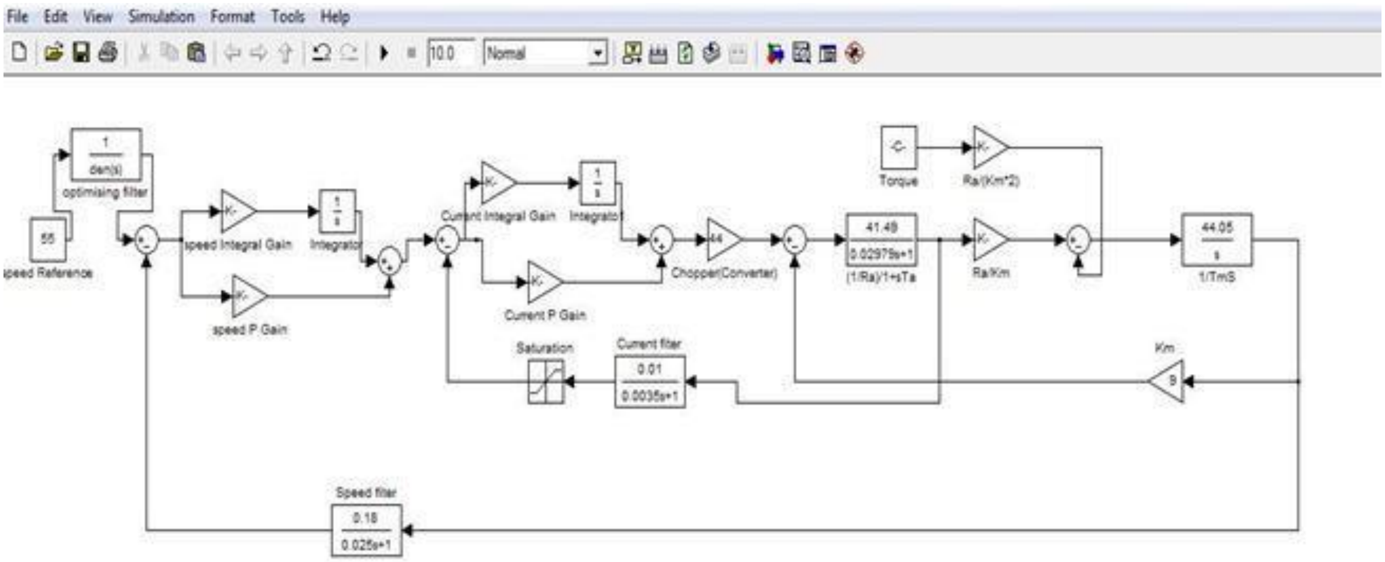

FIGURE 17 SIMULINK MODEL FOR SPEED CONTROL WITH FILTER

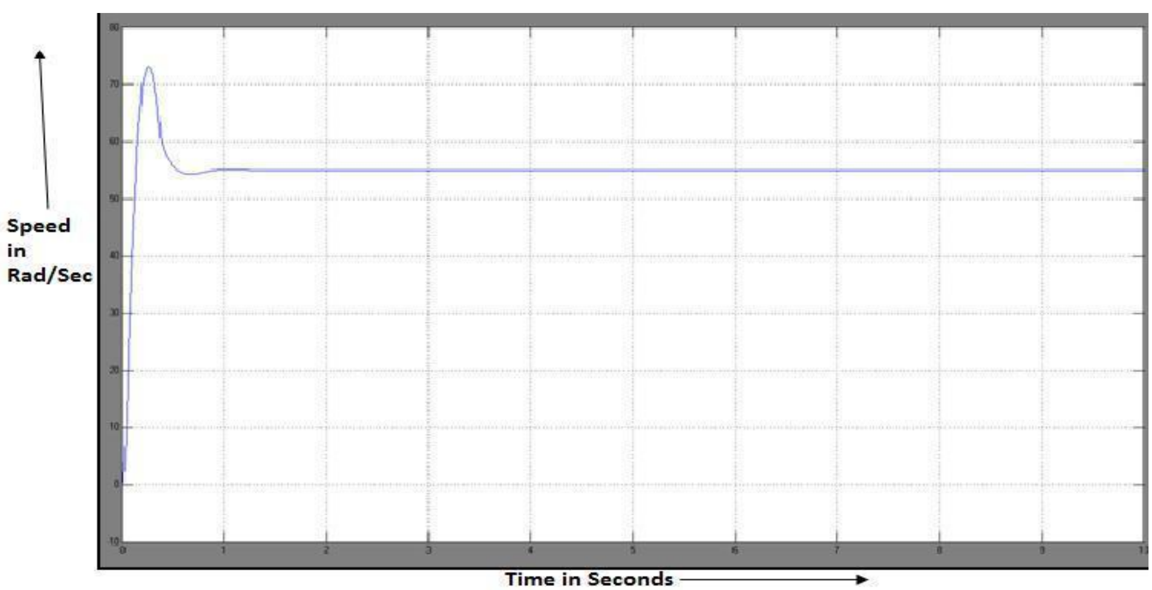

FIGURE 18 SPEED RESPONSE WHEN REF SPEED EQUAL TO RATED SPEED AT FULL LOAD WITHOUT FILTER

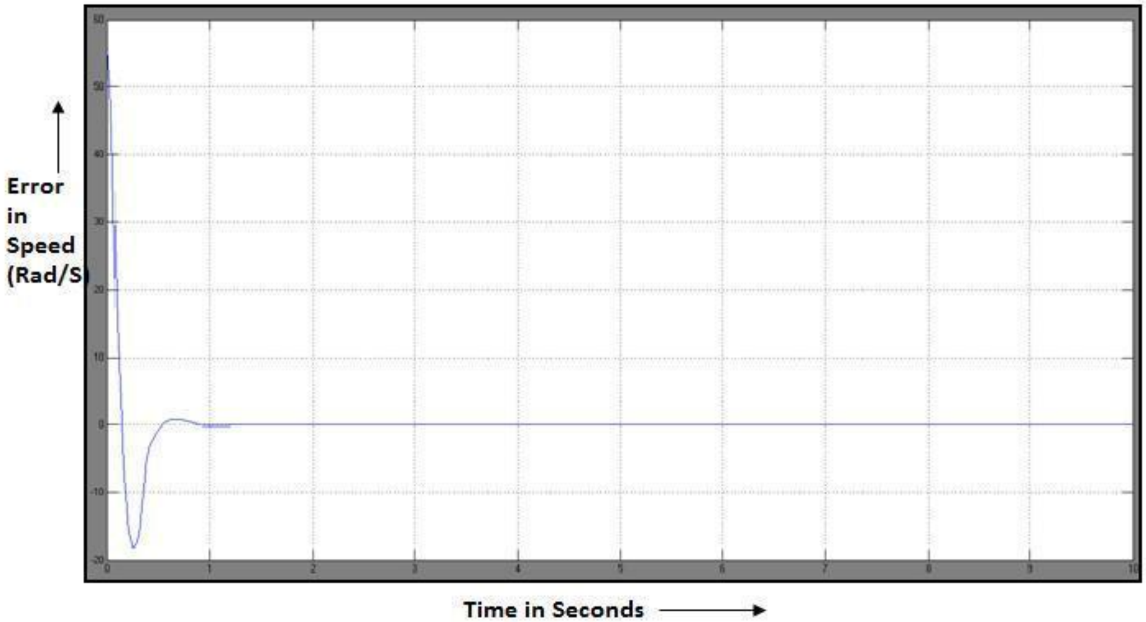

FIGURE 19 ERROR IN SPEED RESPONSE WHEN REF SPEED EQUAL TO RATED SPEED AT FULL LOAD WITHOUT FILTER

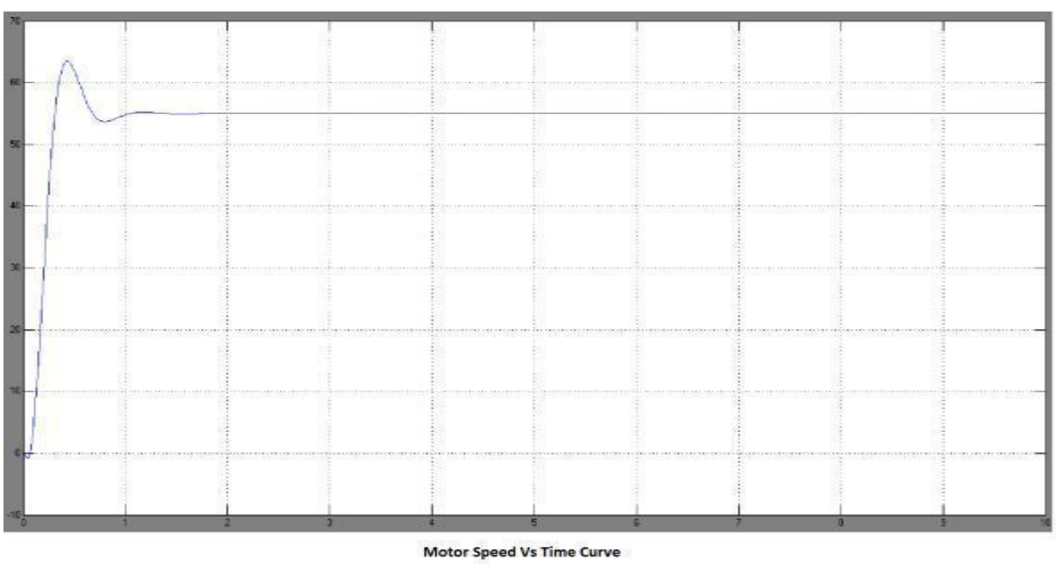

FIGURE 20 SPEED RESPONSE WHEN REF SPEED EQUAL TO RATED SPEED AT FULL LOAD WITH FILTER

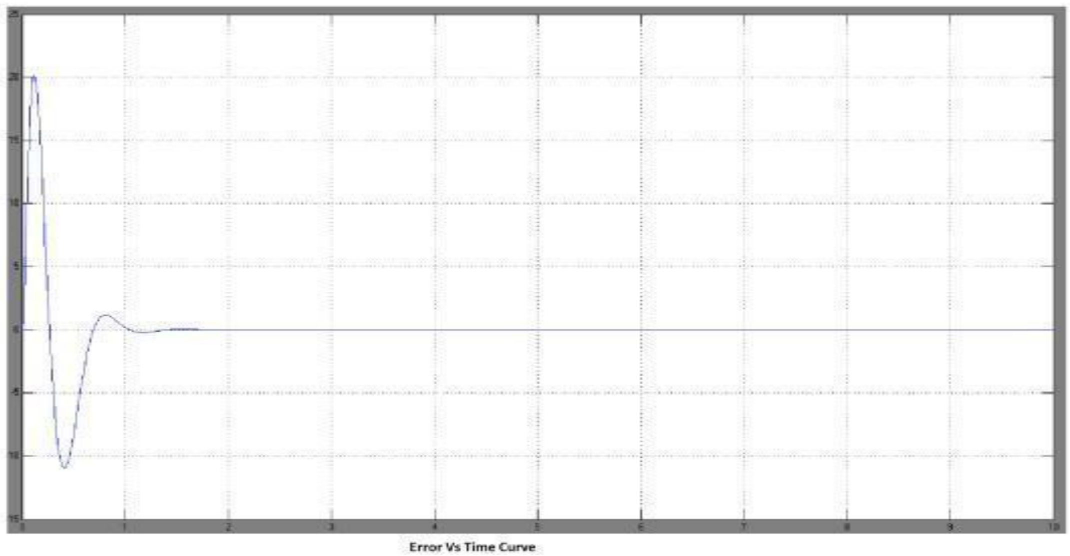

FIGURE 21 ERROR IN SPEED RESPONSE WHEN REF SPEED EQUAL TO RATED SPEED AT FULL LOAD WITH FILTER

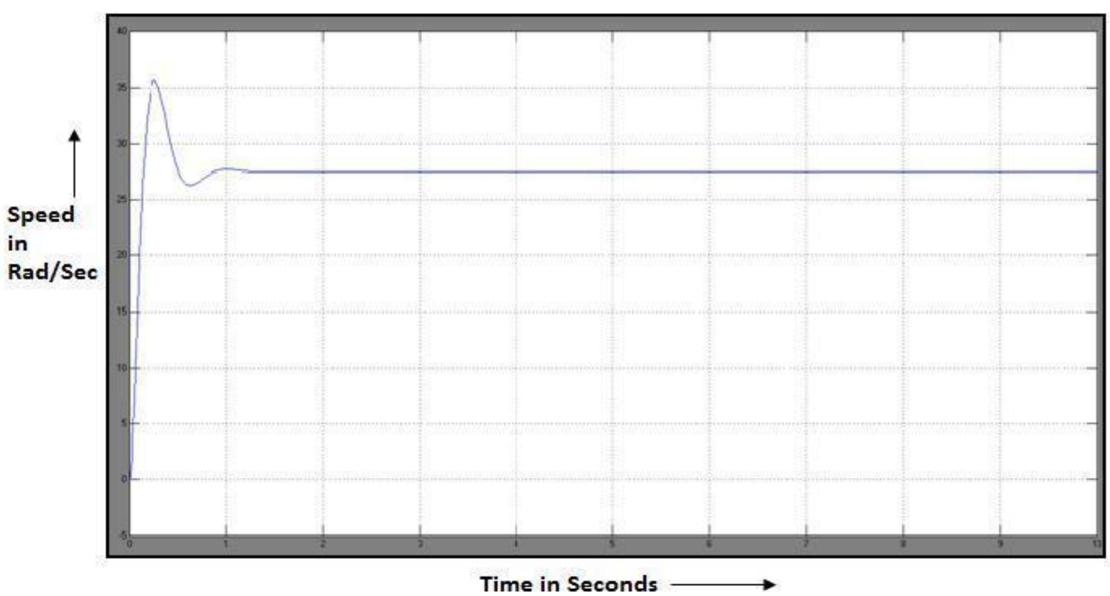

FIGURE 22 SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO HALF THE RATED SPEED AT FULL LOAD

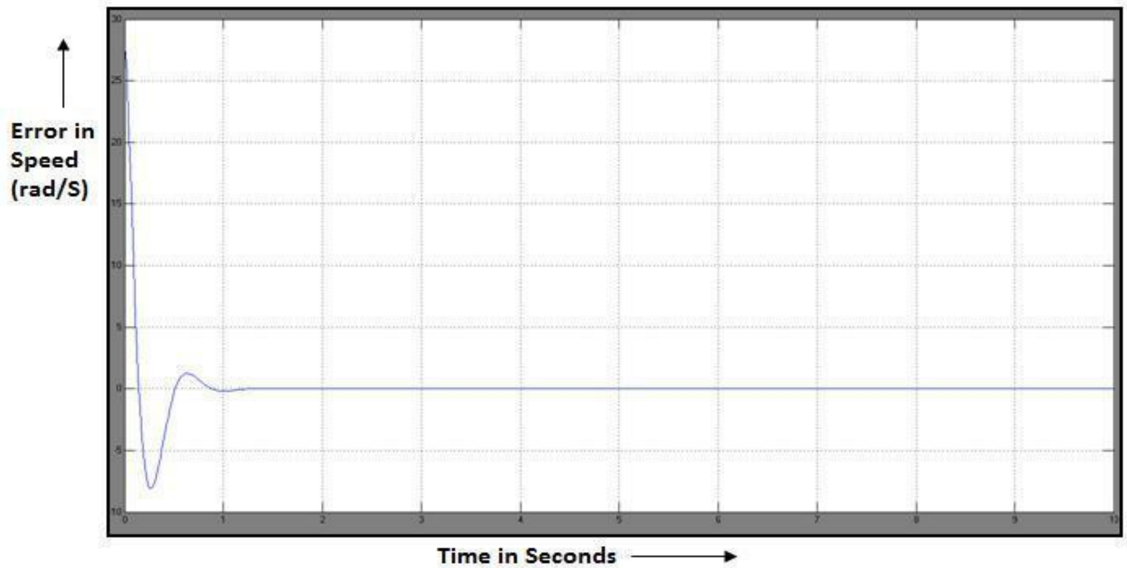

FIGURE 23 ERROR IN SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO HALF THE RATED SPEED AT FULL LOAD

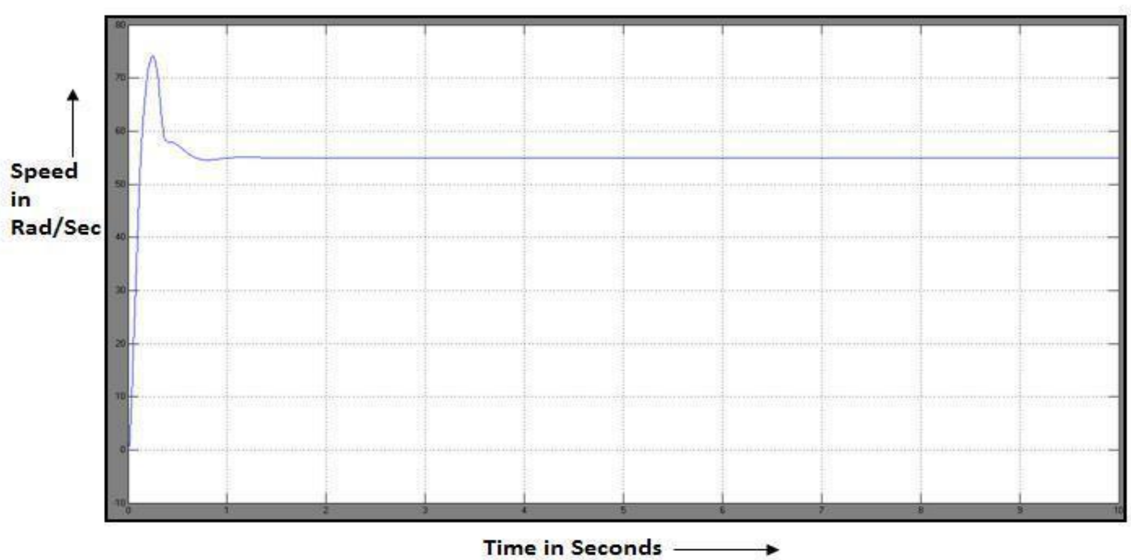

FIGURE 24 SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO THE RATED SPEED AT HALF OF FULL LOAD

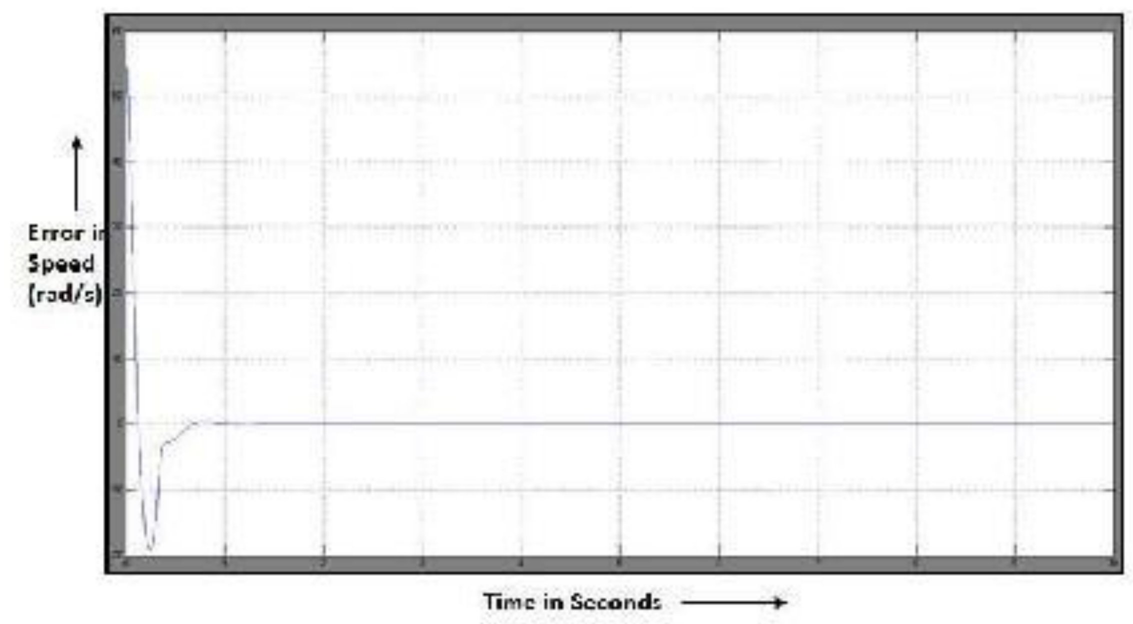

FIGURE 25 ERROR IN SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO THE RATED SPEED AT HALF OF FULL LOAD

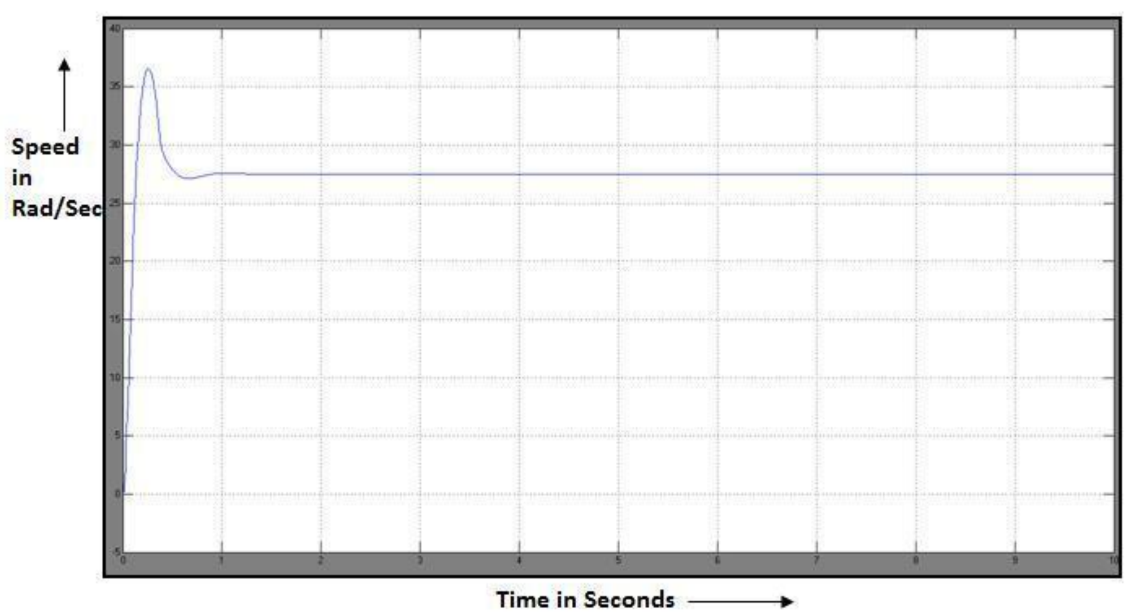

FIGURE 26 SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO HALF THE RATED SPEED AT HALF LOAD

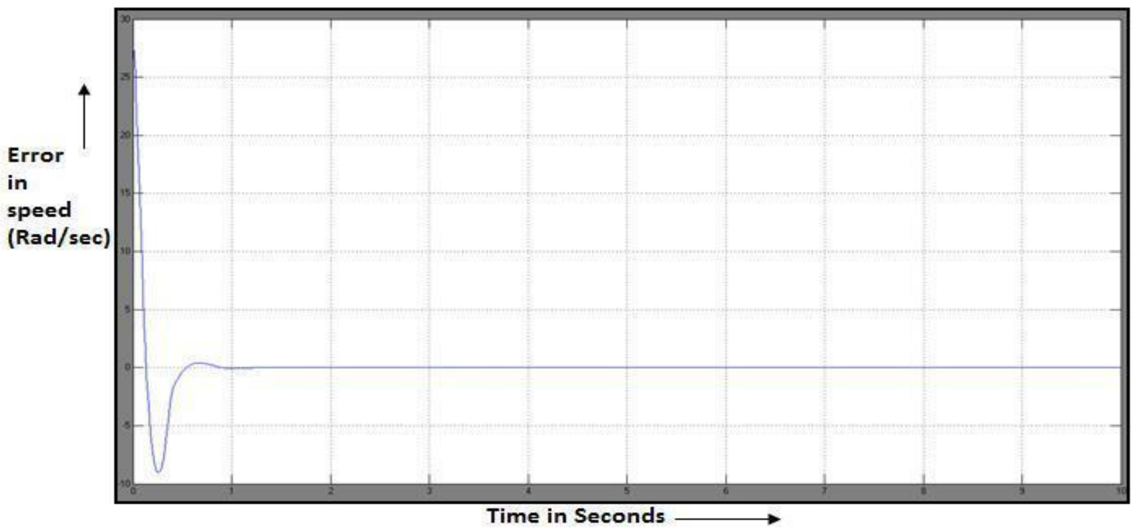

FIGURE 27 ERROR IN SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO HALF THE RATED SPEED AT HALF LOAD

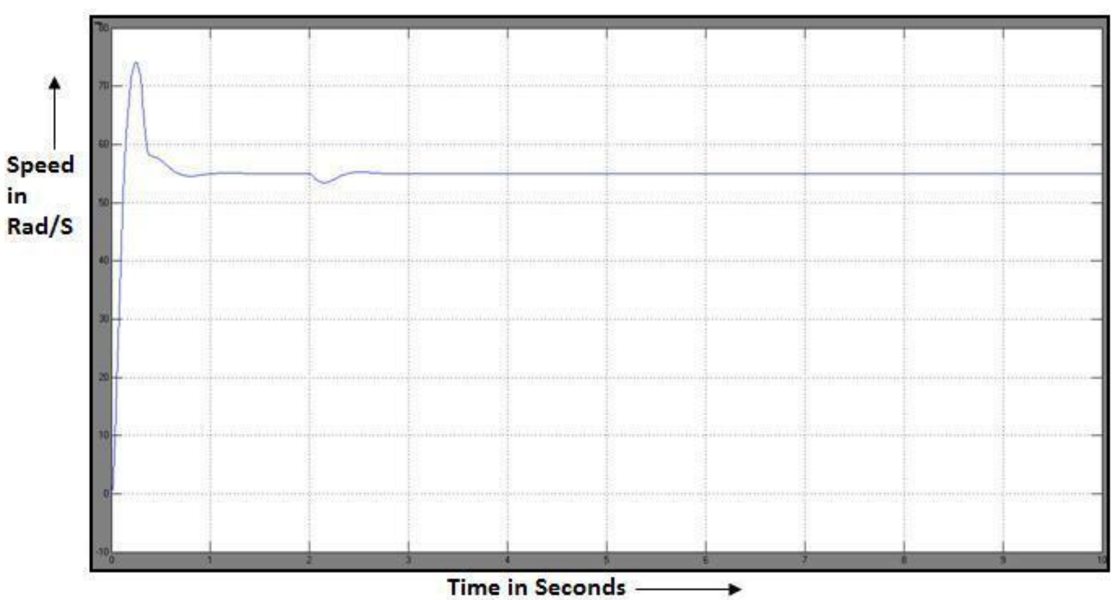

FIGURE 28 SPEED RESPONSE WHEN REFERENCE SPEED IS EQUAL TO THE RATED SPEED WHEN APPLIED TO STEP LOAD TORQUE

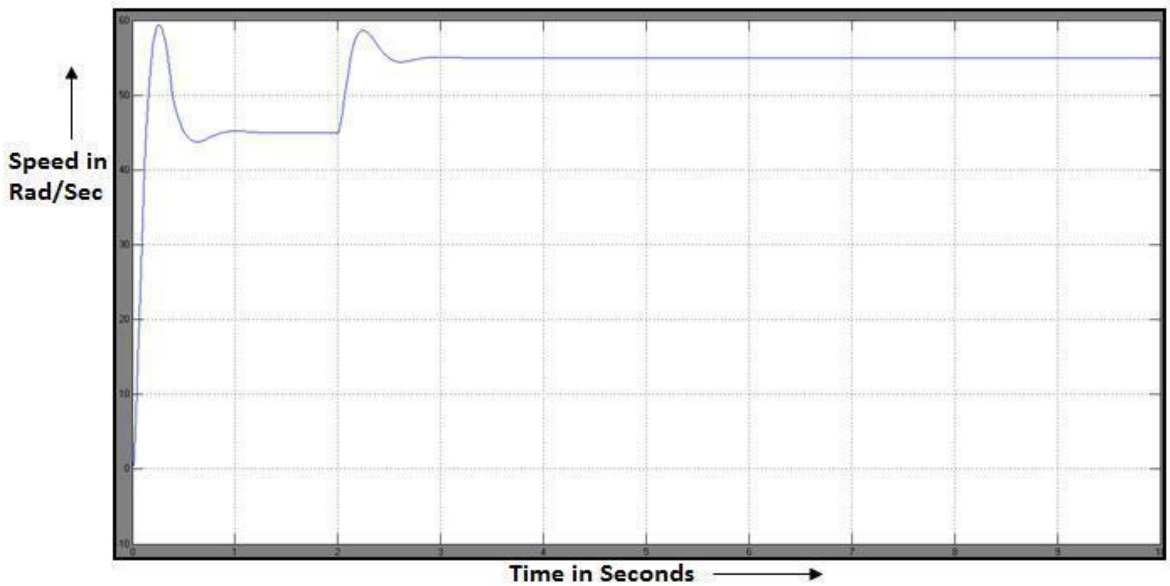

FIGURE 29 SPEED RESPONSE WHEN REFERENCE SPEED IS SAME AS THE RATED SPEED WHEN APPLIED TO CONSTANT LOAD TORQUE

6.2 Conclusion

Here we see that the speed of a dc motor can be successfully controlled by employing a chopper circuit. Here we initially study the basic output characteristics of a MOSFET based chopper and study the output variables for various load characteristics and then we move on towards the simulation of the closed loop model of the dc system involving the chopper and then study it for various change in load torque, rated voltage value and other input parameters. The loops involved are carefully optimized using various mathematical approaches and finally the circuit is simulated and the various plots obtained under various conditions are carefully studied.

6.3 FUTURE SCOPE:

The above described model has been run and tested successfully in MATLAB simulation, so there lies the opportunity to implement the above described model in hardware and study the impact of the approach taken in this thesis report. Moreover in this report we have analyzed only the impact of the approach on separately excited dc motor so there lies the scope to extend the study to various other kinds of motors. Also here we have done the speed control below the rated speed so analysis can also be extended to study the dynamics for above the rated speed using field flux control.

CHAPTER 7-References and bibliography

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